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(54) **Method for motion estimated and compensated Field Rate-Up-conversion (FRU) for video applications, and device for actuating such method**

(57) A method and a device for motion estimated and compensated Field Rate Up-conversion (FRU) for video applications, providing for: a) dividing an image field to be interpolated into a plurality of image blocks (IB), each image block made up of a respective set of image elements of the image field to be interpolated; b) for each image block (K(x,y)) of at least a sub-plurality (Q1,Q2) of said plurality of image blocks, considering a group of neighboring image blocks (NB[1]-NB[4]); c) determining an estimated motion vector for said image block (K(x,y)), describing the movement of said image block (K(x,y)) from a previous image field to a following image field between which the image field to be interpolated is comprised, on the basis of predictor motion vectors (P[1]-P[4]) associated to said group of neighboring image blocks; d) determining each image element of said image block (K(x,y)) by interpolation of two corresponding image elements in said previous and following image fields related by said estimated motion vector. Step c) provides for: c1) applying to the image block (K(x,y)) each of said predictor motion vectors to determine a respective pair of corresponding image blocks in said previous and following image fields, respectively; c2) for each of said pairs of corresponding image blocks, evaluating an error function (err[i]) which is the Sum of luminance Absolute Difference (SAD) between corresponding image elements in said pair of corresponding image blocks; c3) for each pair of said predictor motion vectors, evaluating a degree of homogeneity (H(i,j)); c4) for each pair of said predictor motion vectors, applying a fuzzy rule having an activation level (r[k]) which is higher the higher the degree of homogeneity

neity of the pair of predictor motion vectors and the smaller the error functions of the pair of predictor motion vectors; c5) determining an optimum fuzzy rule having the highest activation level (r[opt]), and determining the best predictor motion vector (P[min]) of the pair associated to said optimum fuzzy rule having the smaller error function; c6) determining the estimated motion vector for said image block (K(x,y)) on the basis of said best predictor motion vector (P[min]).

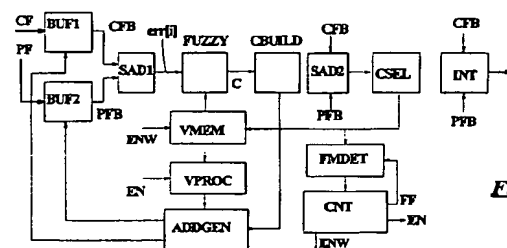


Fig. 17

Description

The present invention relates to a method for motion estimated and compensated Field Rate Up-conversion (FRU) for video applications, and to a device for actuating such method. More particularly, the invention relates to a method based on the so-called "block-matching technique".

The market introduction of high-end TV sets, based on 100 Hz Cathodic Ray Tubes (CRTs), required the development of reliable Field Rate Up-conversion (FRU) techniques, to remove artifacts such as large area flicker and line flicker.

Methods for FRU are known (hereafter referred to as "standard FRU methods") which interpolate the missing image fields to be displayed on the CRT without performing an estimation and compensation of motion of moving objects in successive image fields.

This standard FRU methods are satisfactory in improving the quality of an image and reducing artifacts such as large-area flicker or line flicker. However, when FRU is performed by means of the standard methods new artifacts can appear in the displayed image. In particular, if the image contains moving objects like subtitles, motion judder is introduced. In fact, the interpolation algorithm is not able to detect the objects' motion, and this can lead to interpolated fields wherein the moving objects are displayed in wrong positions.

The problem is better understood by referring to Figure 1, wherein the motion trajectory of a moving object (white squares) in the original (i.e. transmitted and received) image fields is supposed to be a straight line. If the missing fields result from interpolation by means of a standard FRU method (i.e. without motion estimation and compensation), the position of the moving object in the interpolated fields (dark gray squares) is not as expected by the observer (dotted squares).

Such artifacts are visible and induce a blurring effect of fast moving objects, which can reduce considerably the quality of the displayed images.

In order to avoid such a blurring effect and to reduce artifacts, FRU methods have been proposed capable of performing a motion estimation and compensation of moving objects in the image fields. Substantially, motion estimation and compensation provides for detecting the moving parts of the received image fields and interpolating the missing fields according to the estimated motion.

The movement of objects in consecutive image fields can be represented by so-called "motion vectors".

With reference to Figure 2, let's consider an image containing moving objects. Between two consecutive received image fields, the moving objects will have changed their position; for example, object MO which in the previous field (Field T) is in position A, in the current field (Field T+1) is in position B. A motion exists from the previous field to the current field, and this motion can be represented by a vector AB called motion vector.

The motion vector AB represents the motion of object MO from position A in the previous field to position B in the current field: starting from position A in the previous field, applying to object MO the motion vector AB, the object MO is translated into position B in the current field. The position I of the object MO in the missing field (Field T+1/2) that has to be interpolated, must be calculated by the interpolation of the previous field and the current field taking account of the respective positions A and B of the moving object MO. If object MO does not change position between the previous field and the current field, (i.e., if A and B are the same), position I in the missing field is obtained by the translation of A with a motion vector $|AB|/2$. In this way, it is possible to avoid the blurring effect and the missing field is interpolated with the moving object in the right position.

Theoretically, for each pixel of a field a corresponding motion vector could be calculated. However this would enormously increase the number of calculations, and the memory requirements. In the practice, assuming that the dimensions of the objects in the image are always larger than that of a pixel, the image field is divided into image blocks IB (Figure 3), and the motion vector for each block is calculated. The dimension of the blocks in terms of pixels is generally chosen on an experimental basis. The position of a block in a field is identified by the coordinates of the first pixel (upper-left) of this block in this field.

A further assumption which is normally made is that the movement of each block is rigid and translational only.

The method generically provides for detecting the moving blocks in two consequent image fields, and interpolating the missing fields according to the new positions of the blocks.

As shown in Figure 4, a matrix MV (Motion Vectors) is associated to the pattern of blocks of an image field. This matrix MV contains the motion vector of each block of the pattern. To simplify the implementation of the algorithm, it is assumed that the motion vectors of matrix MV correspond to the motion vectors of the blocks of the missing field. To each block K(x,y) of the missing field, that has a pre-definite position x, y (where x and y are the coordinates of the upper-left pixel of the block), there corresponds a motion vector. The position of the block in the missing field is at the middle between the position of a corresponding block B1 in the previous field and the position of a corresponding block B2 in the current field, blocks B1 and B2 being related by the motion vector Y in matrix MV.

Scanning the matrix MV, thanks to the position of the motion vector in the matrix and the value of this motion vector, the position of the blocks B1 and B2 where we have to apply the motion in the previous and current field are easily avail-

able.

Considering a generic block $K(x,y)$ in the missing field to be interpolated, where (x,y) are the coordinates identifying the position of block K , the corresponding vector in matrix MV is a vector $V(dx,dy)$, and the corresponding blocks $B1$, $B2$ in the previous and current field will be at positions:

5 previous field: $B1(x-dx;y-dy)$; current field: $B2(x+dx;y+dy)$. (1)

Thus, once the matrix MV of motion vectors has been built, the motion of each block between consecutive image fields is determined, and the missing fields can be interpolated with the blocks in correct positions.

To build up the matrix MV of motion vectors, the image blocks are scanned starting from the upper-left one down to the bottom-right one. According to the so-called "block-matching" technique, for each image block some neighboring blocks are considered, together with their respective motion vectors; for those neighbouring blocks which precedes the block under examination in the scanning sequence of the image blocks, the already calculated motion vectors are used; for those neighbouring blocks following the block under consideration in the scanning sequence, for which the new motion vectors has not yet been calculated, the motion vectors of the previously calculated and stored matrix MV are used. The motion vector associated to the block under consideration is then calculated on the basis of the motion vectors of the neighbouring blocks.

The method involves a recursive algorithm, and the performance of the method, and thus the results of the displayed image, depends on the choice of the neighbouring blocks and on the way in which the motion vector for the block is calculated starting from the motion vectors of the neighbouring blocks.

In view of the state of the art, it is an object of the present invention to provide a method for motion estimated and compensated FRU.

According to the present invention, such an object is achieved by means of a method for motion estimated and compensated field rate up-conversion providing for:

25 a) dividing an image field to be interpolated into a plurality of image blocks, each image block made up of a respective set of image elements of the image field to be interpolated;
 b) for each image block of at least a sub-plurality of said plurality of image blocks, considering a group of neighboring image blocks;
 c) determining an estimated motion vector for said image block, describing the movement of said image block from a previous image field to a following image field between which the image field to be interpolated is comprised, on the basis of predictor motion vectors associated to said group of neighboring image blocks;
 30 d) determining each image element of said image block by interpolation of two corresponding image elements in said previous and following image fields related by said estimated motion vector; characterized in that step c) provides for:

35 c1) applying to the image block each of said predictor motion vector to determine a pair of corresponding image blocks in said previous and following image fields, respectively;
 c2) for each of said pairs of corresponding image blocks, evaluating an error function which is the Sum of Luminance Absolute Difference (SAD) between corresponding image elements in said pair of corresponding image blocks;
 40 c3) for each pair of said predictor motion vectors, evaluating a degree of homogeneity;
 c4) for each pair of said predictor motion vectors, applying a fuzzy rule having an activation level which is higher the higher the degree of homogeneity of the pair of predictor motion vectors and the smaller the error functions of the pair of predictor motion vectors;
 c5) determining an optimum fuzzy rule having the highest activation level, and determining the best predictor motion vector of the pair associated to said optimum fuzzy rule having the smaller error function;
 45 c6) determining the estimated motion vector for said image block on the basis of said best predictor motion vector.

Also according to the present invention, there is provided a device suitable for performing such a method, characterized by comprising:

50 -) image element storage means for storing image elements of the previous and following image fields for creating a search area in the previous and following image fields;
 -) addressing means for addressing selected image elements in said storage means;
 55 -) motion vector storage means for storing the estimated motion vectors;
 -) first computation means supplied by said storage means for evaluating said error functions associated to said predictor motion vectors;
 -) a fuzzy computation unit supplied by said first computation means and said motion vector storage means for

determining said best predictor motion vector by applying said fuzzy rule to each pair of predictor motion vectors and to the values of the associated error functions;

-) interpolation means supplied by said storage means for determining each image element of said image block by interpolation of two corresponding image elements in said previous and following image fields related by said estimated motion vector.

The features and advantages of the present invention will be made apparent by the following detailed description of a particular embodiment thereof, illustrated by way of a non-limiting example in the annexed drawings, wherein:

Figure 1 schematically shows the results of a standard (non motion compensated) FRU method;
 Figure 2 schematically shows the change of position of a moving object between two consecutive received image fields;
 Figure 3 schematically shows an image field divided in a pattern of image blocks;
 Figure 4 schematically shows the operation of a motion estimated and compensated FRU method;
 Figure 5 schematically shows two quincunx pattern of image blocks of an image field;
 Figure 6 schematically shows an image block for which a motion vector is to be evaluated, and a pattern of neighboring blocks used to perform the method of the invention;
 Figure 7 schematically shows portions of two corresponding image blocks in a previous and in a current image fields;
 Figures 8 to 11 depict membership functions used to perform a fuzzy calculation;
 Figure 12 schematically shows a pattern of motion vectors used to interpolate a motion vector;
 Figures 13 and 14 schematically show a pattern of motion vectors used to implement an "erosion" process;
 Figure 15 schematically shows the interpolation of a pixel of a field to be interpolated;
 Figure 16 schematically shows an interpolation process for determining missing pixels in the previous and current fields;
 Figure 17 is a schematic block diagram of a device according to the invention; and
 Figures 18 to 23 are schematic block diagrams of some blocks of the device of Figure 17.

As described in connection with Figure 3, in order to keep the calculation to be performed to a reasonable number each image field is divided into image blocks IB of equal dimension. As previously mentioned, the dimension of each block IB is determined on an experimental basis; a suitable dimension has proved to be 8x8 pixels of the image frame (containing both the odd lines and the even lines), i.e. 4x8 pixels of the image field (containing either the odd or the even lines). With such dimension, the number of blocks per image field is $(288/4) \times (720/8) = 72 \times 90$ blocks, where 288 is the number of lines and 720 is the number of columns of a field in standard interlaced scanning.

Preferably, in order to further reduce the number of calculations and the required memory resources, instead of evaluating the motion vectors for all the blocks of the image field, only the blocks belonging to either one or the other of the two so-called "quincunx sub-sampling patterns" Q1, Q2 shown in Figure 5 are considered. The division of the field into two quincunx patterns enables to divide the rate of calculation nearly by two. However, it is evident that this is not to be intended as a limitation, because it could be possible to consider all the blocks of the field.

As shown in Figure 6, for each generic block K(x,y) of the chosen quincunx pattern, four neighboring blocks NB[0]-NB[3] are considered, together with their associated motion vectors P[0]-P[3] ("predictor motion vectors"). Experimentally, it has been verified that the best choice involves the nearest blocks in the two diagonal directions; this choice is also compatible with the quincunx sub-sampling of the blocks in the image field. For the two blocks NB[0], NB[1] preceding block K(x,y) in the image block scanning sequence, the values of motion vectors P[0] and P[1] have already been calculated and are available in the current motion vector matrix, while for the blocks NB[2], NB[3] following block K(x,y) the values of motion vectors P[2] and P[3] are extracted from the previous motion vector matrix, which has been previously calculated and stored.

Each one of the four motion vectors P[0]-P[3] is then applied to block K(x,y). In this way, for each motion vector P[1]-P[3] two corresponding blocks, respectively in the current field and in the previous field, are determined, according to equations (1) above. Four pairs of blocks are thus determined.

In order to determine which one of the motion vectors P[i] ($i \in [0;3]$) has the best direction for the block K(x,y) under examination, for each pair of corresponding blocks obtained in the previous and current fields, an error function $err[i]$ is calculated. The error function $err[i]$ is the Sum of the luminance Absolute Difference (SAD), pixel to pixel, between the two corresponding blocks in the previous and current fields:

$$\begin{aligned}
\text{err}[i] &= \text{SAD}(X, Y, P[i]) = \\
&= \sum_{\substack{x \in [0;7] \\ y \in [0;7]}} |\text{lum}(X + x, Y + y, t - 1) - \text{lum}(X + dx + x, Y + dy + y, t)|
\end{aligned}$$

5

where: X,Y are the coordinates of the upper-left pixel of the block found in the previous field; lum(x,y,t) is the luminance of the pixel at position (x,y) in the current field (previous field if instead of t is t-1); P[i] is the motion vector of coordinates (dx, dy).

10 In this way, four error values err[i] are obtained, one for each predictor motion vector P[i].

The components of the generic predictor motion vector P[i] along the coordinate axes x, y are called P[i]x and P[i]y, respectively.

Since each image field contains either the odd or the even lines of an image frame (interlaced transmission standard), the corresponding blocks in the previous and current fields do not contain all the image lines: if for example the previous field is an odd field and the current field is an even field, the block in the previous field contains only the odd lines, while the corresponding block in the current field contains only the even lines. To compute the error function err[i] for any value of the motion vector it is necessary to have, in the corresponding blocks in the previous and current fields, both the odd and the even lines.

20 The algorithm interpolates the missing lines of the blocks necessary for the computation of the error function err[i] depending on the parity of the first line of each block. Assuming that the y-component of the motion vectors is always even, then the first pixel of a block in the previous field and the first pixel of the corresponding block in the current field will belong to image lines with the same line parity.

Referring to Figure 7, where only one case is drawn, the other being obviously symmetrical, in each image block it is necessary to interpolate one line over two. To perform the interpolation, a median filter is advantageously used: the pixels belonging to the missing lines of the block are therefore given by:

$$Px3 = \text{MED}(Px1, Px2, Px4)$$

When the pixel to be interpolated is on the first or the last line of the block, like the pixel Px6 in Figure 7, the pixel just before can be used (if it is possible, otherwise it is possible to use line repetition) to manage this interpolation, and the result is:

$$30 \quad Px6 = \text{MED}(Px4, Px5, Px1).$$

It should be noted that this interpolation depends on the motion vector: in fact, the value of the missing pixel Px3 of the block in the previous field is interpolated using the value of the available pixel Px4 of the corresponding block in the current field, obtained by applying the motion vector P[i]. In this way the quality of the interpolation is greatly improved.

35 So, for each predictor motion vector P[i], two corresponding blocks in the previous and current field are determined, the missing lines of each of the two corresponding blocks are interpolated, and then the corresponding error function err[i] is evaluated.

To see which one of the four predictor motion vectors P[i] fits best the motion of block K(x,y) between the previous and the current field, both the value of the error functions err[i] and a "degree of homogeneity" between each pair of different predictor motion vectors P[i] and P[j] (i,j ∈ [0;3] and i≠j), is analyzed. To do this, according to the invention, a fuzzy computation is performed applying the following fuzzy rule to each pair of predictor motion vectors P[i], P[j]:

"If the vectors P[i] and P[j] are homogeneous and err[i] is small and err[j] is small then this function is high" ; six different pairs of predictor motion vectors exist, so a total of six fuzzy rules are to be evaluated.

To test the degree of homogeneity between two different predictor motion vectors, the following homogeneity value H(i,j) is first computed:

$$45 \quad H(i, j) = |P[i]x - P[j]x| + |P[i]y - P[j]y|.$$

Then a membership function, such as the one depicted in Figure 8, is applied to the homogeneity value H(i,j) to obtain a fuzzy variable h(i,j), whose value indicates the degree of membership of the value of H(i,j) to the fuzzy set "homogeneous". In Figure 8, H1 can be a value preferably comprised between 7 and 14.

50 Similarly, a membership function such as the one depicted in Figure 9 is applied to the value of the error functions err[i] to obtain a fuzzy variable e(i) whose value is indicative of the degree of membership of the value of err[i] to the fuzzy set "small". In Figure 9, err1 is a value preferably comprised between 40 and 70, and err2 is a value preferably comprised between 180 and 200.

Each one of the six fuzzy rules provides a value (activation level of the fuzzy rule) r[k] (k ∈ [0;5]), which is:

$$r[k] = \min(h(i,j), e(i), e(j)).$$

55 Additionally, a further (seventh) fuzzy rule is evaluated:

"If all the err[i] values are high and P[0] and P[1] are high then this function is high".

First the following values are computed:

$$\text{UP}(x) = |P[0]x + P[1]x| ; \text{UP}(y) = |P[0]y + P[1]y|$$

Then a membership function such as the one depicted in Figure 10 is applied to each of the values of UP(x) and UP(y) to obtain two fuzzy variables up(x) and up(y) indicative of the degree of membership of values UP(x) and UP(y) to a first fuzzy set "high". In Figure 10, UP1 is a value preferably comprised between 4 and 9, and UP2 is a value preferably comprised between 12 and 20.

Finally, a membership function such as the one depicted in Figure 11 is applied to the values of the error functions err[i] to obtain a fuzzy variable e'(i) whose value is indicative of the degree of membership of the values of err[i] to a second fuzzy set "high". In Figure 11, err3 is a value preferably comprised between 280 and 320, and err4 is a value preferably comprised between 380 and 420.

The value (activation level) r[6] of the seventh fuzzy rule is given by:

$$r[6] = \min\{e'(0), e'(1), e'(2), e'(3), up(x), up(y)\}$$

The meaning of the values r[k] ($k \in [0;5]$) and r[6] is now discussed.

For each $k \in [0;5]$, the smaller the values of the pair of error functions err[i], err[j] associated to the pair of predictor motion vectors P[i], P[j], and the smaller the difference between the two respective motion vectors P[i], P[j] the higher r[k]; in other words, the activation level r[k] of the corresponding fuzzy rule depends on the sum of absolute luminance difference (SAD) of the pixels of the corresponding blocks in the previous and current field, but also on the degree of homogeneity of the motion vectors.

As regards r[6], the higher the values of the four error functions err[i] associated to the four predictor motion vectors and the greater the predictor motion vectors P[0] and P[1], the higher r[6]. The seventh fuzzy rule has an activation level r[6] which is higher the more the situation is uncertain, i.e. when there is a large movement (P[0] and P[1] high), but none of the four predictor motion vectors seem to provide a good result in terms of error function when applied to the block K(x,y).

The pair of predictor motion vectors P[i] and P[j] for which the function r[k] ($k \in [0;5]$) has the highest value (i.e. the pair of motion vectors for which the corresponding fuzzy rule has the highest activation level among the first six fuzzy rules) is chosen; let's r[opt] denote the highest value among r[0]-r[5]. Among the two predictor vectors P[i] and P[j] associated to said fuzzy rule, the one for which the value of the corresponding error function err[i], err[j] is minimum is called P[min].

A candidate motion vector C is then calculated according to the following algorithm:

if $r[opt] + r[6] \geq R_{th}$, where R_{th} is a prescribed activation level threshold, then the candidate motion vector C has the following components:

$$C_x = \frac{P[min]_x \times r[opt]}{r[opt] + r[6]}$$

$$C_y = \frac{P[min]_y \times r[opt]}{r[opt] + r[6]}$$

Thus, the components Cx and Cy of vector C are respectively equal to $P[min]_x$ and $P[min]_y$, multiplied by a weighting factor that depends on the respective activation levels of the most activated one of the first six fuzzy rules (r[opt]) and of the seventh fuzzy rule (r[6]). It follows that in a situation of uncertainty as to the choice of the best motion vector, the vector 0 is preferred. Thanks to these weighted components, the value of C depends on the characteristics of the different vectors. This means that the components are determined according to both the homogeneity of the predictor motion vectors and the error between the pairs of corresponding blocks obtained by means of the four predictor motion vectors.

If instead $r[opt] + r[6] < R_{th}$, that is if none of the fuzzy rules is sufficiently activated, then candidate vector C is made equal to the predictor motion vector P[i] for which the error function err[i] is the smallest. This means that if the errors err[i] are too high, if the vectors are not homogeneous, then the predictor motion vector with the minimum error value is directly chosen as candidate motion vector for block K(x,y), because the weighting of its components is not reliable.

A suitable value for R_{th} has experimentally been determined to be 0.1.

Vector C thus calculated is the candidate motion vector for the block K(x,y) under examination. This vector could be stored in the motion vector matrix MV in the position corresponding to block K(x,y).

However, in order to improve the estimation of motion of block K(x,y), small perturbations ("updates") are applied to the candidate motion vector C to obtain updated motion vectors; each updated motion vector individuates two corresponding blocks in the previous and current fields; the error functions associated to the updated motion vectors are calculated in the way same previously explained in connection with predictor motion vectors P[i].

The updates applied to candidate motion vector C are the following:

firstly, the following set of four updates is always applied to the components Cx and Cy of vector C:

$$\begin{bmatrix} 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \begin{bmatrix} -1 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ -1 \end{bmatrix}$$

5 Four updated vectors Vu[1]-Vu[4] are obtained, and for each one of these the corresponding error function err is evaluated, in the same way previously described in connection with the predictor motion vectors P[i].

Then, depending on the block K(x,y) under examination, one or the other of the following set of four updates are alternatively applied to the candidate motion vector C:

$$10 \quad \begin{bmatrix} 4 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 2 \end{bmatrix}, \begin{bmatrix} -4 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ -2 \end{bmatrix} \text{ or } \begin{bmatrix} 10 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 4 \end{bmatrix}, \begin{bmatrix} -10 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ -4 \end{bmatrix}$$

Again, four updated vectors Vu[5]-Vu[8] are obtained, and for each one the corresponding error function err is evaluated.

As visible, each update modifies only one of the components Cx and Cy of vector C.

In this way there are obtained, for each block, eight new error function values, each one corresponding to a respective updated vector Vu[1]-Vu[8].

A penalty value is then added to the error function values for the updated vectors, the value of the penalty depending on the value of the update.

To this purpose, the components of vector C Cx and Cy are examined. If the update is added to the component of C of greater value, then a first penalty value PEN1 is added to the error function value associated to that updated vector. If the update is added to the component of C of smaller value, a second penalty value PEN2 is added to the error function value associated to such updated vector, with PEN2>PEN1. Experimentally it has been found that suitable values for PEN1 and PEN2 are respectively 76 and 228. In this way, the updated vectors which have a direction more different from the direction of vector C are somehow penalized in the choice to be made.

The error functions for the updated vectors, added with the respective penalty value, form a set of eight error functions related to eight motion vectors. The updated motion vector providing the smallest error function value is chosen as the motion vector of the block K(x,y) under consideration. Again, to this motion vector will correspond one block in the previous field and one in the current field, determined according to equations (1) above.

Up to now, the way in which the motion vector for a generic image block is estimated has been described. If all the image blocks of the missing image field to be interpolated were submitted to this calculation, a motion vector matrix MV will be straightforwardly built. However, since as previously mentioned a suitable way for reducing the number of calculations consists in estimating the motion vectors of only a subset of the image blocks of a field, namely those blocks belonging to either one or the other of the two quincunx patterns Q1, Q2 depicted in Figure 5, motion vectors for only a half of the image blocks are actually estimated according to the algorithm previously described. The motion vectors of the remaining image blocks are to be interpolated. For the interpolation, median filters are used.

With reference to Figure 12, representing a portion of the motion vector matrix MV, the white squares represent the motion vectors computed by means of the previously described algorithm, while the shaded blocks represent the motion vectors to be interpolated. If the motion vector W is to be interpolated, the four nearest motion vectors V1-V4 which have been estimated by means of the previously described algorithm are considered. The components Wx and Wy of vector W are interpolated in the following way:

$$45 \quad Wx = \text{Med}\left(\frac{V1x + V2x}{2}, V3x, V4x\right)$$

$$Wy = \text{Med}\left(\frac{V1y + V2y}{2}, V3y, V4y\right)$$

50 In this way, the motion vector matrix MV can be completed. For every image block, a corresponding motion vector is provided in the matrix, either estimated by means of the previously described algorithm or interpolated.

The motion vector matrix can be used to interpolate the missing image field taking into account the movement of the image blocks according to the algorithm which will be described later on.

55 However, in order to maximize the uniformity of the motion vector field, the following "erosion" process of the motion vector field (i.e., all the motion vectors of the matrix MV) is performed before actually interpolating the missing field.

Inside the motion vector matrix, patterns of vectors like the one shown in Figure 13 are considered.

Considering a vector E in the center of such a pattern, the corresponding image block is divided in four equal sub-

blocks (Figure 14); for each sub-block of said block, a respective motion vector $\{E_{-1,+1}, \dots, E_{+1,-1}\}$ is determined according to a median filtering performed with vector E and the nearest neighboring vectors $\{Va, Vb, Vc, Vd\}$, as to have the best matching vector possible. In this way, a new ("eroded") vector matrix having four times more elements is obtained. The four sub-vectors $\{E_{-1,+1}, \dots, E_{+1,-1}\}$ are determined as shown in the following table:

Sub-block	Vector
$E_{-1,+1}$	$MED(Va, Vc, E)$
$E_{+1,+1}$	$MED(Va, Vd, E)$
$E_{-1,-1}$	$MED(Vb, Vc, E)$
$E_{+1,-1}$	$MED(Vb, Vd, E)$

The new motion vector matrix, having four times more elements than the starting one, contains motion vectors which fits well to the motion of the picture.

Applying the motion vectors of the matrix to the different blocks of the missing field, the corresponding blocks in the previous and current field can be determined. To each pixel of the current field there corresponds a motion vector that joins the pixel of the current field to a corresponding pixel of the previous field.

As already mentioned, the previous and current fields only contain a half of the lines of an image frame; for example, the previous field contains the odd lines and the current field contains the even lines. The missing lines of each field can be interpolated in a way similar to that used to interpolate the missing pixels of the blocks in performing the evaluation of the error functions, on the basis of the motion vectors. The two fields are thus transformed into progressive fields, containing all the lines of an image frame.

To interpolate the pixels of the missing field the following procedure is used.

Referring to Figure 15, to each pixel PXi of the missing field to be interpolated (Field $T+1/2$ in the figure), a motion vector is assigned checking the image block (more precisely, the sub-block) to which the pixel PXi belongs. This motion vector individuates two corresponding pixels belonging to the previous and to the current field, indicated as PXa and PXb , respectively.

The value of pixel PXi can be determined on the basis of the average value of PXa and PXb , namely: $PXi = (PXa + PXb) / 2$.

Better results are obtained if the following interpolation method is followed. In Figure 15, the pixels individuated in the previous and current field by the zero motion vector crossing the position of pixel PXi are PXa_0 and PXb_0 . The value of pixel PXi is determined by performing the following median filtering:

$$PXi = MED\left(\frac{PXa_0 + PXb_0}{2}, PXa, PXb\right)$$

Let's consider the order the fields are received, and how the original fields and the interpolated ones are output. Field-Rate Upconversion (FRU) provides for outputting two times more fields than the original field-rate. The order is the following:

input field sequence: O_0, E_0, O_1, \dots

output field sequence: $O_0, Ei_{O_0}, Oi_{E_0}, Ei_{E_0}, O_1, \dots$

where:

O_0 : original odd field containing odd image lines;

E_0 : original even field containing even image lines;

Oi_{E_0} : interpolated odd field containing the odd interpolated lines of the original even field at the time of E_0 ;

Ei_{O_0} : interpolated even field containing the even interpolated lines between O_0 and E_0 ;

Ei_{E_0} : interpolated even field containing the even interpolated lines between E_0 and O_1 .

The original odd fields are output without any change. Fields Ei_{O_0} and Ei_{E_0} are interpolated according to the algorithm previously described, taking into account the motion of objects between fields O_0 and E_0 , and E_0 and O_1 , respectively.

To interpolate the field Oi_{E_0} , the motion vector field calculated to estimate motion between fields O_0 and E_0 is

already available, so that the pixels PX of the odd lines missing in field E_0 are computed by the three-point median filtering among the pixels PX1, PX2 and PX3, where PX1 and PX2 are the available pixels of the current field E_0 surrounding the missing pixel PX, and PX3 is the pixel of the previous field O_0 pointed by the motion vector associated to pixel PX (Figure 16).

Up to now motion of objects between two adjacent fields has been assumed to be present. This is the case when the image field sequence originates from a television camera (camera mode).

But when the image field sequence is originated from a movie, motion between two adjacent fields will take place only once over a couple of image frames. This is due to the particular procedure followed to transmit the movie material. Typically, a movie contains 24 pictures per second. For television broadcasting, the 24 pictures per second are converted into 25 image frames per second. In interlaced scanning, each image frame contains two interlaced image fields; so, each movie picture is converted into two image fields. Obviously, when two fields originate from the same movie picture, no motion exists between the two fields. Motion only exists between fields originating from different movie pictures, i.e. once over a couple of image frames.

Since the previously described interpolation algorithm is recursive, and when no motion exists between two consecutive fields the motion vector matrix only contains zero vectors, problems exist when at the next field (belonging to the next movie picture) motion is to be estimated, because the information of motion estimated two fields in advance has got lost. Thus, it is necessary to perform the interpolation of the missing fields according to the type of transmitted material.

To select the proper motion estimation behavior and the proper sequence of the interpolated field a film-mode detector is needed.

The proposed solution is based on accumulating (i.e., summing) the motion vectors of each vector matrix, and comparing the accumulated values between two adjacent fields.

Assuming that A_p and A_c are the accumulated motion vectors relating to the previous and current field, respectively, the normal camera mode is obtained whether the ratio between A_c and A_p (A_c/A_p) is approximately equal to 1, or it has the same trend (always increasing or always decreasing) when two adjacent frames are considered.

A register R is used to store proper values related to the A_c/A_p ratio, namely:

$R=0$ if $1-Th \leq |A_c/A_p| \leq 1+Th$;
 $R=1$ if $|A_c/A_p| > 1+Th$;
 $R=2$ if $|A_c/A_p| < 1-Th$,

where Th is a proper threshold value.

To distinguish between camera mode and film mode, the following rules are used:

- 1) If $[1-Th \leq |A_c/A_p| \leq 1+Th]$ and $[R = 0]$ then camera_mode;
- 2) If $[|A_c/A_p| < 1-Th]$ and $[R = 1]$ and $[current_field_parity = even]$ then film_mode(phase_0);
- 3) If $[|A_c/A_p| > 1+Th]$ and $[R = 2]$ and $[current_field_parity = odd]$ then film_mode(phase_0);
- 4) If $[|A_c/A_p| > 1+Th]$ and $[R = 2]$ and $[current_field_parity = even]$ then film_mode(phase_1);
- 5) If $[|A_c/A_p| < 1-Th]$ and $[R = 1]$ and $[current_field_parity = odd]$ then film_mode(phase_1);
- 6) else camera_mode.

Current field parity is to be considered, because the change between two movie pictures can occur either between a next odd and a previous even field, or between a next even and a previous odd field, i.e. two different film phases (film_mode(phase_0) and film_mode(phase-1)) exist.

If camera mode is detected, the previously described interpolation algorithm is performed.

If differently film mode is detected, the method provides for outputting the following field sequence (supposing that motion exists between the even field of an image frame and the odd field of the following frame):

input field sequence: O_0, E_0, O_1, \dots

output field sequence: $O_0, E_0, O_{i_{E_0}}, E_{i_{E_0}}, O_1, \dots$

where:

O_0 : original odd field (odd image lines);

E_0 : original even field (even image lines, no motion with respect to O_0);

O_1 : original odd field (odd image lines, following image frame, motion with respect to E_0);

$O_{i_{E_0}}$: interpolated odd field (odd image lines, compensation of motion between E_0 and O_1);

$E_{i_{E_0}}$: interpolated even field (even image lines, compensation of motion between E_0 and O_1).

A block diagram of a device suitable for implementing the motion estimated and compensated FRU previously

described is depicted in Fig. 17.

In the drawing, PF and CF indicate the streams of pixels of the previous and current image fields, respectively, as received and stored in respective field memories (not shown).

PF and CF are respectively supplied to buffer units BUF1 and BUF2, suitable to create, according to the block-matching technique, portions ("search areas") of the previous and current image fields.

The outputs PFB, CFB of BUF1 and BUF2, determined by an address generator block ADDGEN that generates addresses for addressing the pixels stored in blocks BUF1 and BUF2, supply a block SAD1 which for each generic block $K(x,y)$ (Fig. 6) performs the evaluation of the four error functions $err[i]$ ($i \in [0;3]$) associated to the four initially chosen predictor motion vectors $P[i]$ of the four neighboring blocks $NB[i]$; PFB and CFB also supply another block SAD2, performing the evaluation of the eight error functions err associated to the set of eight updated vectors $Vu[1]-Vu[8]$, calculated by block CBUILD.

Due to the spatial and temporal recursive approach of the previously described algorithm, a storage unit VMEM is required to store the already estimated motion vectors, both belonging to the current and the previous vector matrix.

Blocks SAD1 and VMEM supply a block FUZZY which implements the fuzzy calculation previously described, and determines the components of the candidate motion vector C.

The output of block FUZZY (i.e., the candidate motion vector C) supplies block CBUILD which applies to the components of vector C the previously described sets of updates, to determine the eight updated motion vectors $Vu[1]-Vu[8]$.

Block ADDGEN determines the proper image blocks pointed by the selected motion vector; block ADDGEN is supplied by the output of block VPROC and the output of block CBUILD.

The values of the error functions associated to the eight updated motion vectors $Vu[1]-Vu[8]$, evaluated by block SAD2, are supplied to block CSEL, which, according to the algorithm previously described, selects among the eight updated vectors $Vu[1]-Vu[8]$ the motion vector (having the smallest associated error function) to be associated to the current image block $K(x,y)$ as estimated motion vector; this vector is then stored in the vector storage unit VMEM. A block VPROC is provided to evaluate (i.e., interpolate) the motion vectors for the image blocks not belonging to the chosen quincunx pattern, for which the fuzzy computation is not performed.

Also, block CSEL supplies a block FMDET, which is able to discriminate between camera mode and film mode according to the algorithm previously described. A control unit CNT is also provided which, in response to the result of the evaluation performed by block FMDET, controls the blocks VMEM and VPROC. Control unit CNT generates two control signals EN and ENW, respectively supplied to blocks VPROC and VMEM. Signal EN is activated when block VPROC has to interpolate a motion vector not belonging to the chosen quincunx pattern, but is deactivated during the motion estimation phase; signal ENW is activated to store the motion vector at the output of block CSEL into block VMEM.

At the end an interpolator block INT, supplied by the outputs PFB and CFB of BUF1 and BUF2, is provided to interpolate the pixels of the missing field according to the estimated motion vectors; the estimated motion vector, at the output of block VPROC, is supplied to block ADDGEN to determine the addresses of the corresponding pixels in the previous and current fields related by the estimated motion vector. The interpolator block INT then performs the interpolation of the missing pixel according to the median filtering previously described.

In the following the architecture of the main blocks of the device will be described.

Blocks BUF1 and BUF2 have the same structure depicted in Figure 18. The purpose of these two blocks is to store part of the image pixels of the previous and current fields in order to implement a search area in both the previous and the current image fields. The search area dimension is larger than the blocks among which the match is computed and its dimension determines how big is the maximum motion vector that can be estimated.

Basically, each block BUF1, BUF2 is composed by a plurality of line memories LM which store the image lines of the search area, and pixel delays PD.

The number of line memories LM affects the maximum vertical component of the motion vector that can be estimated; the number of pixel delays PD affects the maximum horizontal component of said motion vector.

Figure 19 shows one of four identical units composing block SAD 1.

For each generic block $K(x,y)$ for which the respective motion vector is to be evaluated, block SAD1 evaluates the four error functions $err[i]$ associated to the four predictor motion vectors $P[i]$. Each vector $P[i]$ individuates two corresponding image blocks in the previous and current fields, respectively. In order to evaluate the matching degree of the two blocks pointed by the motion vector $P[i]$, the associated error function $err[i]$ is to be evaluated. Also, it has to be remembered that the corresponding image blocks in the previous and current fields have to be transformed into progressive format, to include all the image lines.

This is done by blocks MF1 and MF2, which perform a median filtering to interpolate the missing pixels in each block (according to the algorithm previously described in connection with Figure 7). In the drawing:

CF_CL: current field, current line;

CF_PL: current field, previous line;
 PF_CL: previous field, current line;
 PF_PL: previous field, previous line.

5 The outputs of the median filters, together with PF_CL or, respectively, CF_CL are supplied to a respective subtractor block SUB1, SUB2, which performs the absolute difference of the luminance value of the pixels in the corresponding blocks; the outputs of the two subtractors are then stored in an accumulator block ACC.

To better understand the architecture of block SAD1, let us suppose an image block, once transformed into progressive format, has a dimension of $8 \times 8 = 64$ pixels. This means that in order to transform the block into progressive
 10 format, 32 out of the 64 pixels must be interpolated for each image block. Thus, to compute the error function between two corresponding image blocks in the previous and current fields, 64 median filters and 64 subtractors are needed. The accumulator block ACC provides the cumulative error $err[i]$. Since block SAD1 has to calculate the error functions $err[i]$ related to the four predictor motion vectors $P[i]$, it has to contain four units equal to that shown in Figure 19.

The inner architecture of block FUZZY is shown in Figure 20. Depending on considerations based on the uniformity
 15 of the four predictor motion vectors $P[i]$ and on the associated error functions $err[i]$, a fuzzy process will create the candidate motion vector C.

The Fuzzy Process basically consists of two parts: the first one is formed by blocks M1, M2 and RC1 and implements an inference (the first six fuzzy rules previously described) based on the degree of homogeneity and on the
 20 respective error functions $err[i]$ of the four predictor vectors $P[i]$ in order to select the best predictor vector among the previous four ($P[\min]$); the second one is formed by blocks M3, M4 and RC2 and implements a sort of fall-back fuzzy rule (the seventh fuzzy rule previously described) when all the predictor vectors $P[i]$ have high error functions $err[i]$ and extents, so that the zero vector is in this case selected.

More particularly, block M1 implements the membership function shown in Figure 8 (on the basis of the values $H(i,j)$ calculated by homogeneity evaluator block HE), M2 implements the membership functions shown in Figure 9, and block
 25 RC1 evaluates the activation levels $r[k]$ ($k = 0-5$) of the first six fuzzy rules previously described; the output of block RC1 is therefore formed by the six activation levels $r[k]$. Block M3 implements the membership function depicted in Figure 11, M4 implements the membership functions depicted in Figure 10 (one for the two components $UP(x)$, $UP(y)$, calculated by extent evaluator block EE), and block RC2 evaluates the activation level $r[6]$ of the seventh fuzzy rule; the output of block RC2 is therefore formed by the activation level $r[6]$.

30 The four predictor vectors $P[i]$ are provided to block FUZZY by block VMEM; the values of the four error functions $err[i]$ are provided by block SAD1.

The output $r[k]$ ($k=0-5$) of block RC1 is supplied to a block RS (Rule Selector) which selects the one among the first six fuzzy rules having the highest activation level ($r[\text{opt}]$). As previously described, two of the four predictor vectors $P[i]$, $P[j]$ are associated to each one of the first six fuzzy rules. Once the fuzzy rule with the highest activation level $r[\text{opt}]$ has
 35 been determined, the predictor vector having the minimum error function between the two predictors associated to such a fuzzy rule is selected by block VS (Vector Selector). This vector $P[\min]$ ("best predictor") is supplied, together with the value $r[\text{opt}]$ provided by block RS and the value $r[6]$ provided by block RC2, to a block RC (Rule Composition) which calculates the components C_x , C_y of the candidate motion vector C according to the formula previously described; block RC is also supplied by the values $err[i]$ and by the four predictor vectors $P[i]$, because as previously described when
 40 none of the seven fuzzy rules has a sufficiently high activation level, the predictor vector having the smallest error function is chosen as vector C.

The structure of block CBUILD is depicted in Figure 21. This block is supplied by vector C, and determines the eight updated vectors $Vu[1]-Vu[8]$.

Block SP splits vector C into its components C_x , C_y along the X and Y axes. Block HU provides the horizontal components of the sets of updates, which are added to C_x ; similarly, block VU provides the vertical components of the sets
 45 of updates, which are added to C_y . Block MC merges the horizontal and vertical components $Vu[n]_x$, $Vu[n]_y$ ($n=1-8$) of the updated vectors. The inner structure of blocks SP and MC depends on the particular data structure used to represent the motion vectors.

The eight updated vectors $Vu[1]-Vu[8]$ are supplied to block SAD2, which is composed of eight units identical to that
 50 shown in Figure 19.

Block CSEL adds to the eight error functions calculated by block SAD2 the correct penalty values PEN1, PEN2. Then Block CSEL compares the eight error function values with added penalties, to determine the minimum error function value and the associated vector, which can be one of the eight updated vectors $Vu[n]$. The vector with the minimum error function value is selected as estimated motion vector for the block $K(x,y)$ under examination.

Basically block CSEL is composed by adders (to add the penalty to the error functions associated to the eight
 55 updated vectors, calculated by block SAD2) and block suitable of evaluating the minimum among eight elements.

The structure of block VPROC is shown in Figure 22. As previously stated, the motion vector field is preferably estimated for a quincunx sub-sampled pattern of blocks. The missing motion vectors have to be interpolated. Block VPROC

comprises a block VINT performing the interpolation previously described in connection with Figure 12 for obtaining the missing motion vectors. Block VPROC also comprises a block VER performing the "erosion" process previously described in connection with Figures 13 and 14. Block VINT is supplied by the output of block VMEM; the output of block VER supplies a multiplexer block MUX which is also supplied directly by the output of block VMEM. Control signal EN provided by block CNT selects the behavior of block VPROC, which must be active during the interpolation of the output vector field and not during the motion estimation phase.

Block FMDET has the structure shown in Figure 23.

The input V of block FMDET represents the currently estimated motion vector, provided at the output of block CSEL; this vector is accumulated by block VACC with the other motion vectors previously estimated and relating to the same image field; at the output of block VACC the value Ac is obtained. FF is a 100 Hz clock signal corresponding to the output field frequency, and supplies a register DELAY used to store the cumulated motion vector field relating to the a field, and to output said cumulated value at the time of the following field; the output of register DELAY is Ap.

A divider block DIV computes the ratio $|Ac/Ap|$, while a comparator block CMP determines which condition is satisfied (i.e. $|Ac/Ap| = 1$, or $|Ac/Ap| > 1 + Th$, $|Ac/Ap| < 1 - Th$). The result of this comparison is stored in a register R. A block LG implements the boolean rules 1) to 5) previously described.

The output MODE (MODE=camera_mode, MODE=film_mode(phase0), MODE=film_mode(phase 1)) of block LG is supplied to block CNT so that the proper control signals EN, ENW can be generated only when required, i.e. only when motion estimated and compensated field interpolation is to be performed.

Block INT implements the required computation to interpolate the pixels of the missing field. Basically, it is composed by an adder and a median filter.

Other methods can be used in order to exploit the motion information. This is not restrictive for the purpose of the invention.

Claims

1. Method for motion estimated and compensated Field Rate Up-conversion (FRU) for video applications, providing for

- a) dividing an image field to be interpolated into a plurality of image blocks (IB), each image block made up of a respective set of image elements of the image field to be interpolated;
- b) for each image block (K(x,y)) of at least a sub-plurality (Q1,Q2) of said plurality of image blocks, considering a group of neighboring image blocks (NB[0]-NB[3]);
- c) determining an estimated motion vector for said image block (K(x,y)), describing the movement of said image block (K(x,y)) from a previous image field to a following image field between which the image field to be interpolated is comprised, on the basis of predictor motion vectors (P[0]-P[3]) associated to said group of neighboring image blocks;
- d) determining each image element of said image block (K(x,y)) by interpolation of two corresponding image elements in said previous and following image fields related by said estimated motion vector; characterized in that step c) provides for:

- c1) applying to the image block (K(x,y)) each of said predictor motion vectors to determine a respective pair of corresponding image blocks in said previous and following image fields, respectively;
- c2) for each of said pairs of corresponding image blocks, evaluating an error function (err[i]) which is the Sum of luminance Absolute Difference (SAD) between corresponding image elements in said pair of corresponding image blocks;
- c3) for each pair of said predictor motion vectors, evaluating a degree of homogeneity (H(i,j));
- c4) for each pair of said predictor motion vectors, applying a fuzzy rule having an activation level (r[k]) which is higher the higher the degree of homogeneity of the pair of predictor motion vectors and the smaller the error functions of the pair of predictor motion vectors;
- c5) determining an optimum fuzzy rule having the highest activation level (r[opt]), and determining the best predictor motion vector (P[min]) of the pair associated to said optimum fuzzy rule having the smaller error function;
- c6) determining the estimated motion vector for said image block (K(x,y)) on the basis of said best predictor motion vector (P[min]).

2. Method according to claim 1, characterized in that said group of neighboring image blocks (NB[0]-NB[1]) comprises a first sub-group of image blocks (NB[0],NB[1]) preceding the image block (K(x,y)) in the scanning sequence of said

sub-plurality of image blocks, and a second sub-group of image blocks (NB[2],NB[3]) following the image block in said scanning sequence.

3. Method according to claim 2, characterized in that said group of neighboring image blocks (NB[0]-NB[3]) comprises the four image blocks nearest neighboring to said image block (K(x,y)) in the diagonal directions.
4. Method according to claim 3, characterized in that said evaluating a degree of homogeneity (H(i,j)) comprises computing the sum of absolute differences between the components of said pair of predictor motion vectors (P[i],P[j]) along two orthogonal axes (x,y).
5. Method according to claim 4, characterized in that said applying a fuzzy rule comprises determining a fuzzy set "small" for the values of the error functions, determining a degree of membership of the error functions (err) to said fuzzy set "small", determining a first fuzzy set "high" for the values of the degree of homogeneity, and determining a degree of membership of the degree of homogeneity to the fuzzy set "high".
6. Method according to claim 5, characterized in that said activation level (r[k]) of a fuzzy rule comprises determining the minimum among the degree of membership of the degree of homogeneity to the first fuzzy set "high" and determining the degrees of membership of the error functions associated to the predictor motion vectors (P[i],P[j]) to which the fuzzy rule is applied to the fuzzy set "small".
7. Method according to any one of claims 2 to 6, characterized in that step c6) provides for choosing as estimated motion vector for said image block (K(x,y)) said best predictor motion vector (P[min]).
8. Method according to any one of claims 2 to 6, characterized in that step c) further provides for applying a further fuzzy rule having an activation level (r[6]) which is higher the higher the error functions of the predictor motion vectors (P[0]-P[3]) and the higher the predictor motion vectors (P[0],P[1]) associated to the blocks of said first sub-group (NB[0],NB[1]), and determining a candidate estimated motion vector (C) of said image block (K(x,y)) as a weighted average between the best predictor motion vector (P[min]) and the zero vector, the respective weights being the activation level (r[opt]) of said optimum fuzzy rule and the activation level (r[6]) of said further fuzzy rule.
9. Method according to claim 8, characterized in that said applying a further fuzzy rule comprises determining a first value (UP(x)) and a second value (UP(y)) which are the sum of the absolute components, respectively along the two axes (x,y), of the two predictor motion vectors (P[0],P[1]) associated to said first sub-group of blocks (NB[0],NB[1]), determining a second fuzzy set "high" for the first and second values, determining respective degrees of membership of the first and second values to the second fuzzy set "high", determining a third fuzzy set "high" for the values of the error functions (err[i]), determining respective degrees of membership (e'(i)) of the error function values (err[i]) to the third fuzzy set "high".
10. Method according to claim 9, characterized in that the evaluation of the activation level (r[6]) of the further fuzzy rule comprises determining the minimum among the degrees of membership to the second fuzzy set "high" of the first and second values (UP(x),UP(y)) and the degrees of membership of the error functions (err[i]) to the third fuzzy set "high".
11. Method according to any one of claims 8 to 10, characterized in that step c6) provides for choosing as estimated motion vector for said image block (K(x,y)) said candidate estimated motion vector (C).
12. Method according to any one of claims 8 to 10, characterized in that step c) further provides for applying to said candidate estimated motion vector (C) a set of updates for obtaining a corresponding set of updated motion vectors (Vu[1]-Vu[8]) and evaluating the error functions (err) associated to said updated motion vectors.
13. Method according to claim 12, characterized in that the updated motion vector having the minimum error function is chosen as the estimated motion vector for said block (K(x,y)).
14. Method according to claim 12, characterized in that respective penalty values (PEN1 ,PEN2) are added to the error functions (err) associated to said updated motion vectors (Vu[1]-Vu[8]), the penalty values depending on the difference in direction between the updated motion vectors and the candidate estimated motion vector (C).
15. Method according to any one of the preceding claims, characterized in that said sub-plurality (Q1,Q2) of the plural-

ity of image blocks is made up of image blocks belonging to either one or the other of two complementary quincunx patterns.

16. Method according to claim 15, characterized in that the motion vectors (W) for each image block not belonging to said sub-plurality of image blocks (Q1,Q2) are determined by interpolating the estimated motion vectors (V1-V4) of respective neighboring blocks belonging to said sub-plurality.

17. Method according to claim 16, characterized in that after having determined the estimated motion vector for said image block (K(x,y)), the image block (K(x,y)) is further divided into four sub-blocks, and motion vectors ($E_{-1,+1}$ - $E_{+1,-1}$) for each of said sub-blocks are calculated as averages between the estimated motion vector for said image block (K(x,y)) and motion vectors (Va-Vd) associated to respective neighboring image blocks.

18. Method according to any one of the preceding claims, characterized in that said evaluating an error function (err[i]) for each of pairs of corresponding image blocks in the previous and following image fields comprises transforming the two corresponding image blocks into progressive format.

19. Method according to any one of the preceding claims, characterized by:

determining if a received image field sequence (O_0, E_0, O_1) originates from a video camera or from a movie; and if the received image field sequence originates from a camera, for each pair of received image fields determining an interpolated intermediate image field by performing steps a) to d);
if the received image field sequence originates from a movie, determining an intermediate image field by performing steps a) to d) only for alternate pairs of received image fields, said alternate pair of fields comprising two fields belonging to different image frames.

20. Method according to claim 19, characterized in that said determining if the received image field sequence originates from a video camera or from a movie provides for:

for each current received image field, evaluating a current accumulated value (Ac) of the estimated motion vectors describing movement of the image blocks between a previous received image field and said current received image field;
evaluating a current ratio ($|Ac/Ap|$) between the current accumulated value (Ac) and a previous accumulated value (Ap) of the estimated motion vectors describing movement of the image blocks between a further previous received image field and said previous received image field;
determining if said received field sequence originates from a movie on the basis of the value of said current ratio, the value of a previous ratio associated to the three previous received image fields preceding said current received image field, and a parity of the current received image field.

21. Device suitable for actuating the method according to any one of the preceding claims, characterized by comprising:

-) image element storage means (BUF1,BUF2) for storing image elements of the previous and following image fields for creating a search area in the previous and following image fields;
-) addressing means (ADDGEN) for addressing selected image elements in said storage means;
-) motion vector storage means (VMEM) for storing the estimated motion vectors;
-) first computation means (SAD1) supplied by said storage means for evaluating said error functions (err[i]) associated to said predictor motion vectors (P[i]);
-) a fuzzy computation unit (FUZZY) supplied by said first computation means and said motionvector storage means for determining said best predictor motion vector (P[min]) by applying said fuzzy rule to each pair of predictor motion vectors (P[i]) and to the values of the associated error functions;
-) interpolation means (INT) supplied by said storage means for determining each image element of said image block (K(x,y)) by interpolation of two corresponding image elements in said previous and following image fields related by said estimated motion vector.

22. Device according to claim 21, characterized in that said fuzzy computation unit (FUZZY) comprises an homogeneity evaluator (HE) for evaluating the degree of homogeneity ($H(i,j)$) of each pair of the predictor motion vectors (P[i]), a first membership evaluator (M1) supplied by said degree of homogeneity for determining a degree of membership of the degree of homogeneity to a first fuzzy set "high", a second membership evaluator (M2) supplied by said error

- functions (err[i]) for determining a degree of membership of the error functions to a fuzzy set "small", a first rule computation unit (RC1) supplied by the first and second membership evaluators for determining the activation level (r[k]) of said fuzzy rules, a rule selector (RS) supplied by the first rule computation unit for determining the fuzzy rule having the highest activation level (r[opt]), and a vector selector (VS) supplied by the rule selector and the predictor motion vectors (P[i]) for determining said best predictor motion vector (P[min]).
- 5
23. Device according to claim 22, characterized in that said fuzzy computation unit (FUZZY) further comprises a third membership evaluator (M3) supplied with said error function values (err[i]) for determining a degree of membership of the error function values to a second fuzzy set "high", an extension evaluator (EE) supplied with the predictor motion vectors (P[min]) for determining a first value (UP(x)) and a second value (UP(y)) providing a measure of extension of the predictor motion vectors respectively along two coordinate axes (x,y), a fourth membership evaluator (M4) for determining a degree of membership of the first and second values to the third fuzzy set "high", a second rule computation unit (RC2) supplied by the third and fourth membership evaluators (M3,M4) for determining the activation level of a further fuzzy rule, a rule composition unit (RC) supplied by the rule selector (RS), the vector selector (VS) and the second rule computation unit (RC2) for determining said candidate estimated motion vector (C).
- 10
24. Device according to claim 23, characterized by comprising a vector updating block (CBUILD) supplied by the fuzzy computation unit (FUZZY) for applying to the candidate estimated motion vector (C) a set of updates for obtaining updated motion vectors (Vu[1]-Vu[8]), second computation means (SAD2) for evaluating error functions associated to said updated motion vectors, and a candidate selector (CSEL) supplied by said second computation unit for determining the updated motion vector having the minimum associated error function.
- 15
25. Device according to claim 24, characterized in that said vector updating block (CBUILD) comprises a vector component splitter (SP) for determining the components (Cx,Cy) along said coordinate axes (x,y) of said candidate estimated motion vector (C), a first and a second adders (ADD1 ,ADD2) for respectively adding to each component of the candidate estimated motion vector a respective update value, and a vector component merger (MC) for merging together said components.
- 20
26. Device according to any one of claims 21 to 25, characterized by comprising detector means (FMDET) for detecting if a received image field sequence (O₀,E₀,O₁) originates from a video camera or from a movie.
- 25
27. Device according to claim 26, characterized in that said detector means (FMDET) comprises a vector accumulation means (VACC) for calculating a current accumulated value (Ac) of the estimated motion vectors describing movement of the image blocks between a previous received image field and a current received image field; a first register (DELAY) for storing a previous accumulated value (Ap) of the estimated motion vectors describing movement of the image blocks between a further previous received image field and said previous received image field; a divider means (DIV) for evaluating a current ratio (|Ac/Ap|) between the current accumulated value (Ac) and the previous accumulated value (Ap); a second register (R) for storing the value of a previous ratio associated to the three previous received image fields preceding said current received image field, and means (CMP,LG) for determining if said received field sequence originates from a movie on the basis of the value of said current ratio, the value of said previous ratio and a parity of the current received image field.
- 30
- 35
- 40
- 45
- 50
- 55

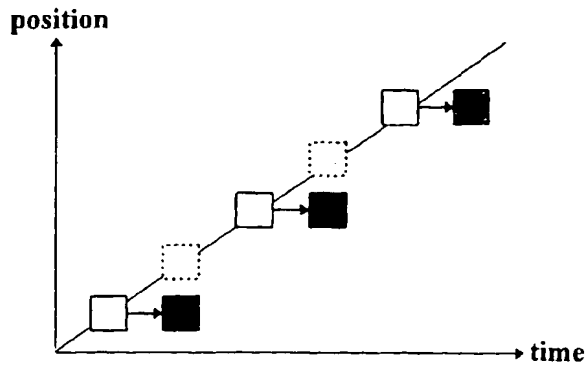


Fig. 1 (PRIOR ART)

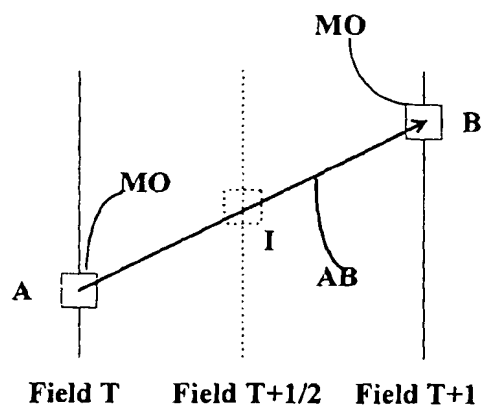


Fig. 2 (PRIOR ART)

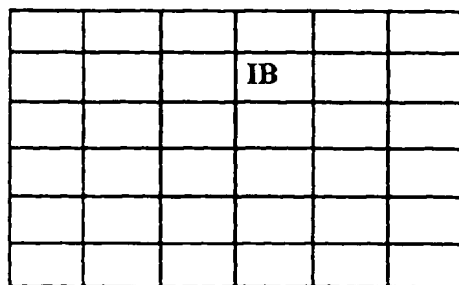


Fig. 3 (PRIOR ART)

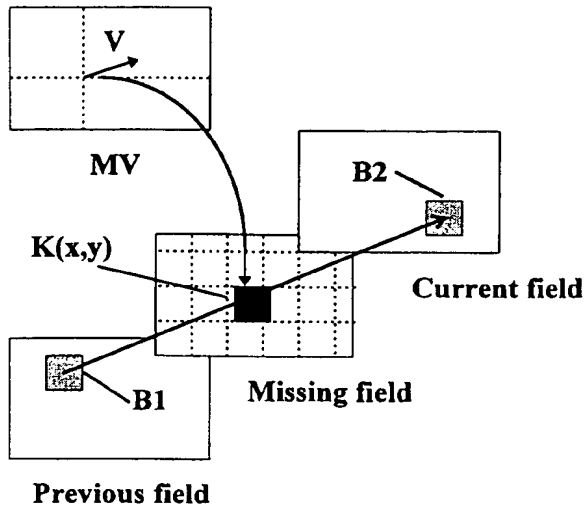
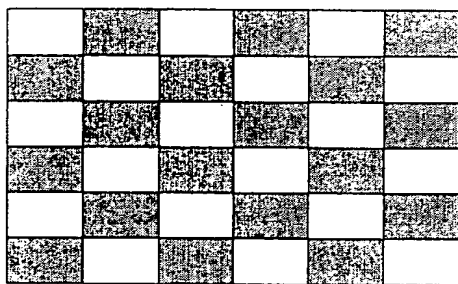


Fig. 4 (PRIOR ART)





 Q1
 Q2

Fig. 5

NB[0] (P[0])		NB[1] (P[1])
	K(x,y)	
NB[2] (P[2])		NB[3] (P[3])

Fig. 6

0.5

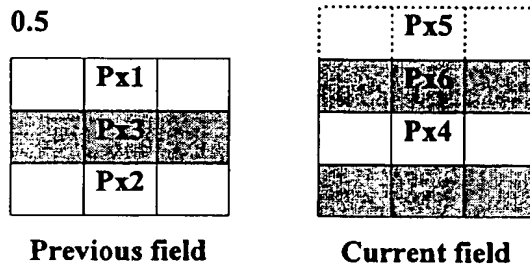


Fig. 7

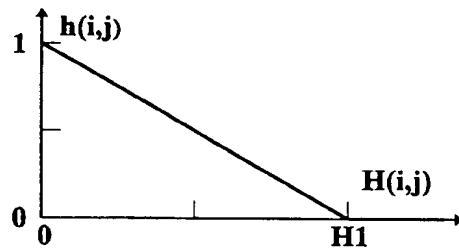


Fig. 8

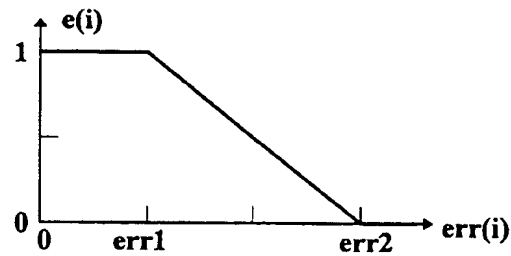


Fig. 9

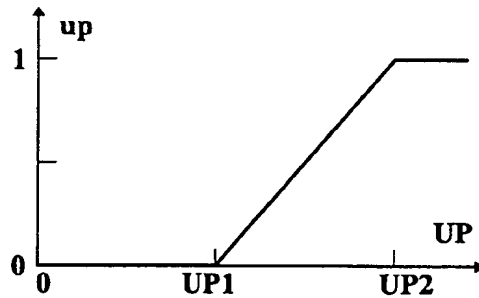


Fig. 10

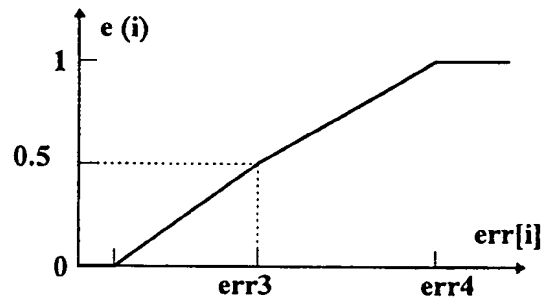


Fig. 11

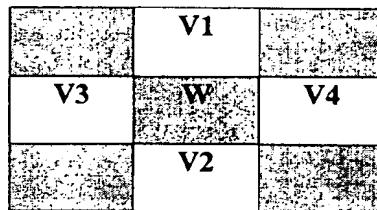


Fig. 12

Vectors computed
 Vectors to be interpolated

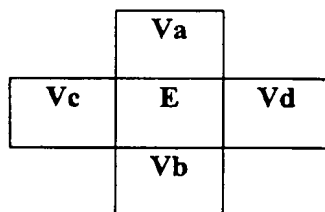


Fig. 13

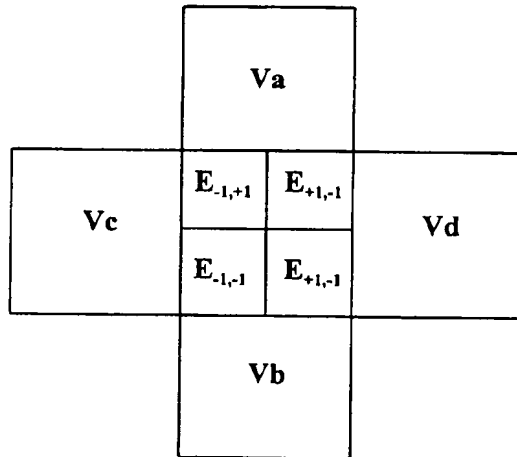


Fig. 14

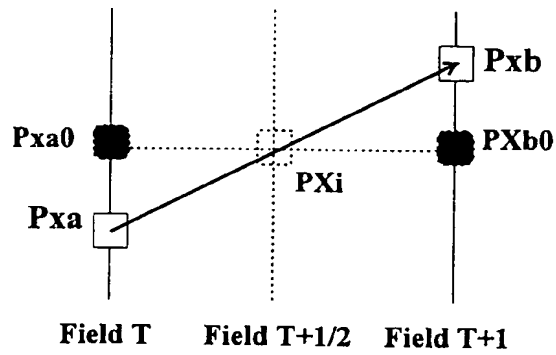


Fig. 15

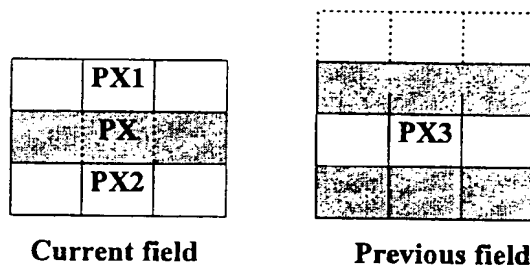
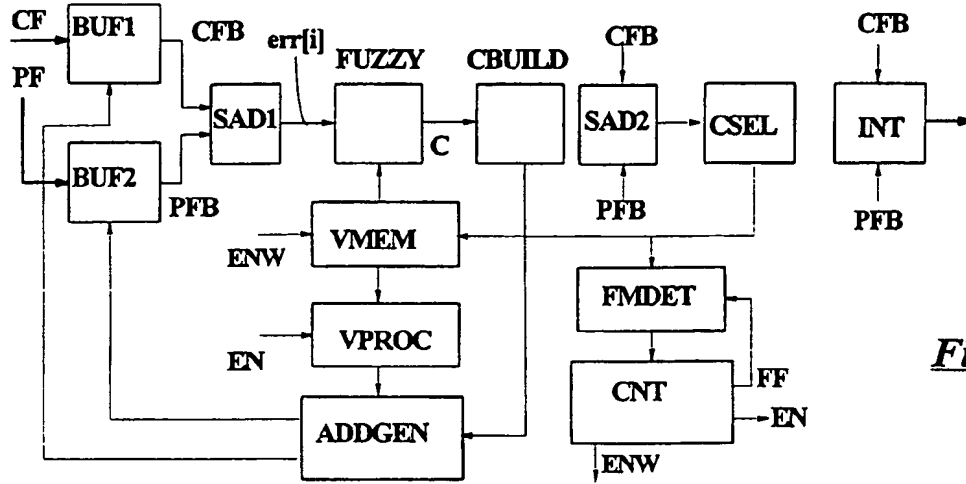
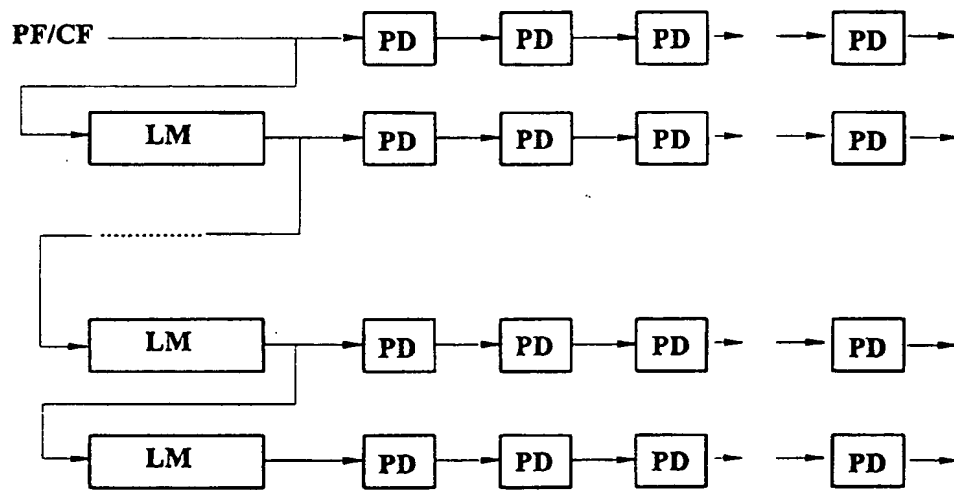


Fig. 16

*Fig. 17**Fig. 18*

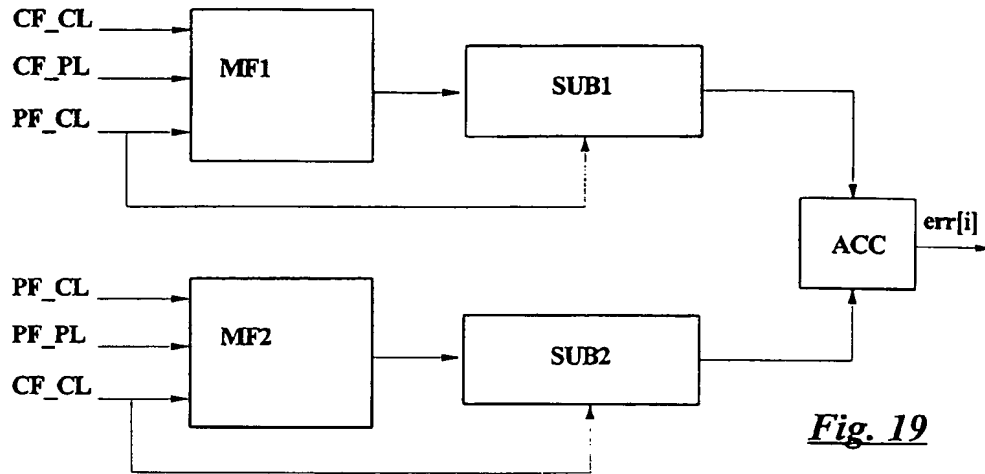


Fig. 19

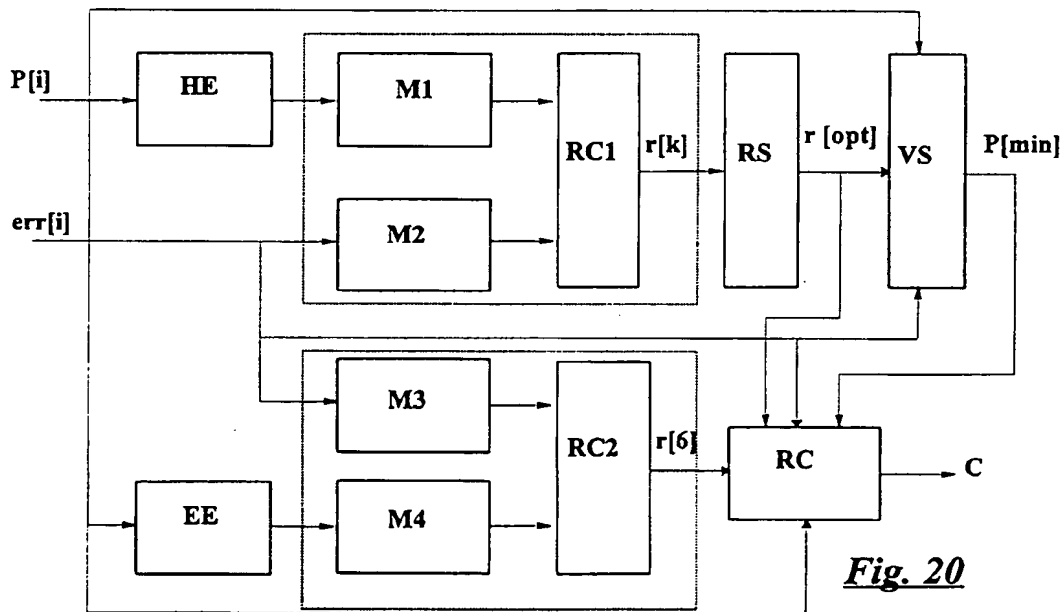


Fig. 20

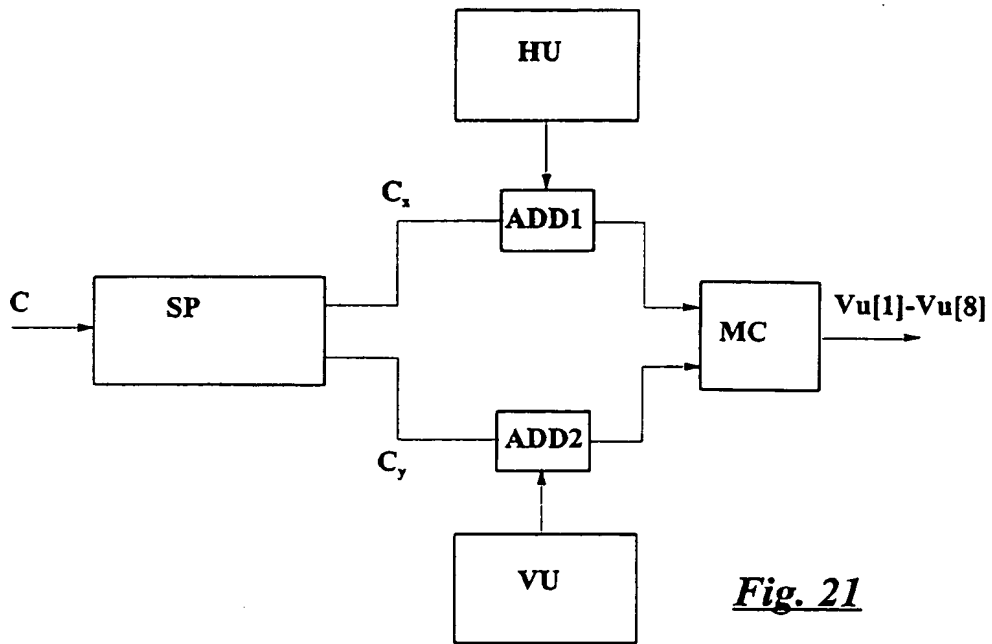


Fig. 21

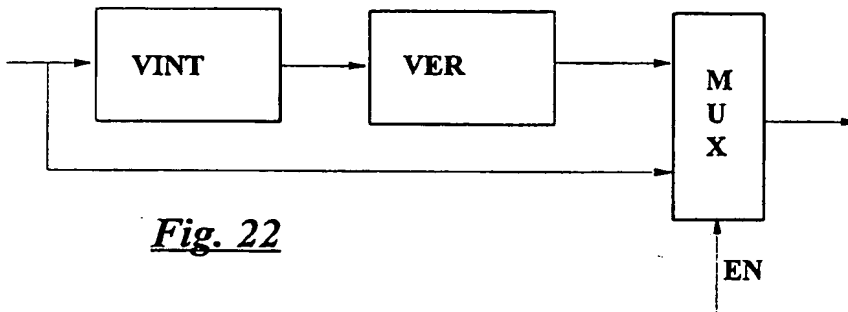


Fig. 22

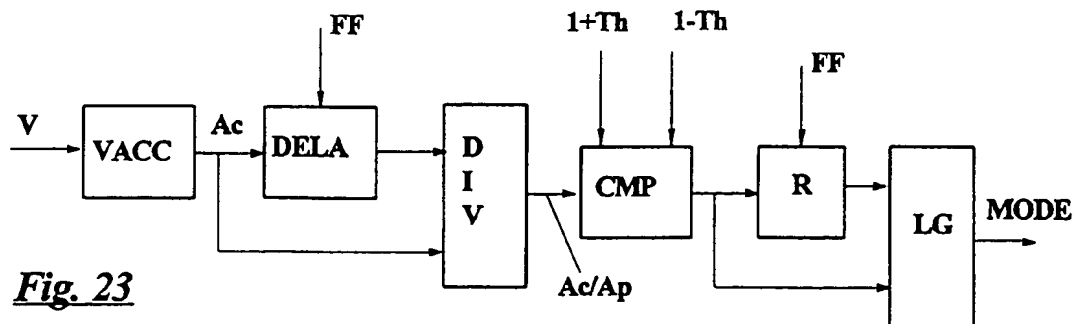


Fig. 23



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 83 0188

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 650 293 A (SELECO SPA) 26 April 1995 * page 6, line 14 - page 8, line 17 * ---	1,21	H04N7/01 H04N5/44
A	KOIVUNEN T ET AL: "Motion estimation using combined shape and edge matching" SIGNAL PROCESSING: IMAGE COMMUNICATION, JUNE 1994, NETHERLANDS, vol. 6, no. 3, ISSN 0923-5965, pages 241-252, XP000451928 * page 246, left-hand column, line 13 - right-hand column, line 31 * ---	1,21	
A	EP 0 684 726 A (CO RI M ME CONSORZIO PER LA RI ;SGS THOMSON MICROELECTRONICS (IT)) 29 November 1995 * the whole document * ---		
A	BRUBAKER D I: "Fuzzy-logic system solves control problem" EDN, 18 JUNE 1992, USA, vol. 37, no. 13, ISSN 0012-7515, pages 121-126, 128, XP000301374 * the whole document * -----		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H04N
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 17 September 1997	Examiner Beaudoin, O
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document</p>			

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